Interference of light

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Overview

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Goals

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Milestones

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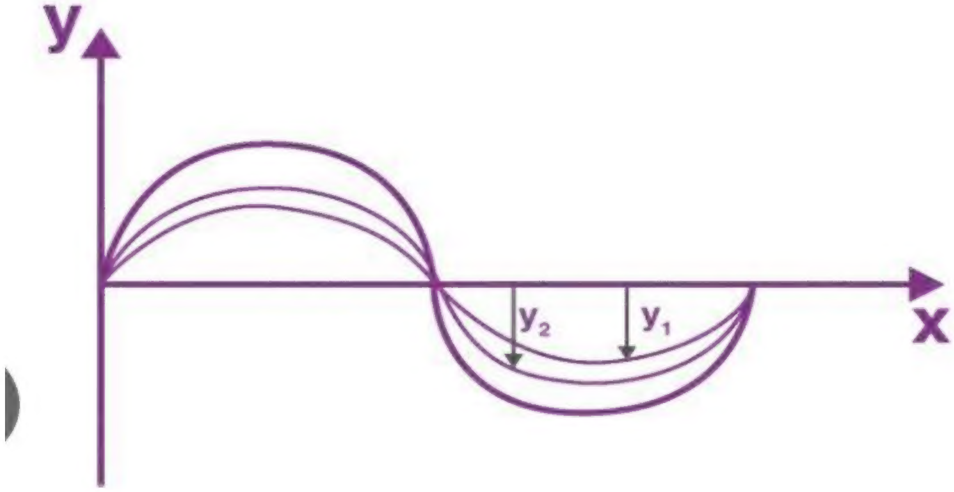
INTERFERENCE OF LIGHT

INTRODUCTION : The term interference refers to a phenomenon involving superposition of waves leading to a modification of their intensity in the region of superposition. At certain points the intensity may become more than the sum of intensities of the individual waves and at certain other points it may tend zero. The former is known as constructive interference

and the latter is called destructive interference .

However the use of terms are misleading . Actually it causes redistribution of light rather than destruction or construction of light.

Principle of superposition



When two or more light wave travels through a medium, the resultant displacement at any point is the vector sum of the displacement due to each wave. This is the principle of superposition of waves which forms the basis of interference.

Let y1 be the displacement due to one wave at any instant and let y2 be the displacement of the other wave at the same instant. Then resultant displacement is y = y1 y2

Interference of Light

When two or more light waves of the same frequency and amplitude with a constant phase difference travel in the same direction, superimpose upon each other, the resultant intensity of light is not distributed uniformly in space. This non uniform distribution of the light intensity due to the superposition of light waves is called interference.

At some points, the intensity is a maximum and the interference at these points is called constructive interference. Here, the crest of one wave falls on the crest of another wave and trough of one wave falls on the trough of another wave.

At some points, the intensity is minimum and the interference at these points is called destructive interference. Here the crest of one wave falls on the trough of the other and the trough of one wave falls on the crest of another wave.

So when two or more light waves interfere, we get alternate dark and bright bands of equal width.

These bands are called interference fringes. This phenomenon of interference is in accordance with the law of conservation of energy.

Condition for constructive interference: Path difference = n where n = 0, 1,2, 3,......

Condition for destructive interference: Path difference = (2n+1)

2

where n = 0, 1,2, 3,......

Conditions for sustained interference pattern

By sustained interference, we mean that the nature and order of interference at a point of the medium should remain unchanged with time. The two conditions for this to happen are

(i) The interfering waves must be coherent.

(ii) The two sources must have zero phase difference or must have constant phase difference.

(iii) The path difference between the waves must be less than or equal to coherence length.

Types of Interference

Interference of light waves can either be constructive interference or destructive interference.

Constructive interference: Constructive interference takes place when the crest of one wave falls on the crest of another wave such that the amplitude is maximum. These waves will have the same displacement and are in the same phase.

Destructive interference: In destructive interference, the crest of one wave falls on the trough of another wave such that the amplitude is minimum. The displacement and phase of these waves are not the same

Conditions for interference of light

For obtaining a light interference pattern that is sustained or retained, some conditions need to be fulfilled. They are:

1.The light source must be coherent and in the same state of polarisation.

2.The amplitudes and intensities of the light sources should be equal. This will ensure there is sufficient contrast between the maxima and the minima of the interference pattern.

3.The light source must be monochromatic and a point source. E.g., lasers.

4.The sources of light must be near enough to produce clear and sharp fringes.

The source and screen should be far enough to produce wide but sharp fringes.

Coherent sources

Two waves are said to be coherent,

(i) If they emit light waves with a constant phase difference between them

(ii) If they have same frequency (or wavelength) and same amplitude.

(iii) Eg: Two slits illuminated by a monochromatic source.

Characteristics of Coherent Sources

Coherent sources have the following characteristics:

1.The waves generated have a constant phase difference

2.The waves are of a single frequency

Coherent Source Example

Laser light is an example of a coherent source of light. The light emitted by the laser light has the same frequency and phase.

Sound waves are another example of coherent sources. The electrical signals from the sound waves travel with the same frequency and have constant phase difference.

Incoherent Sources

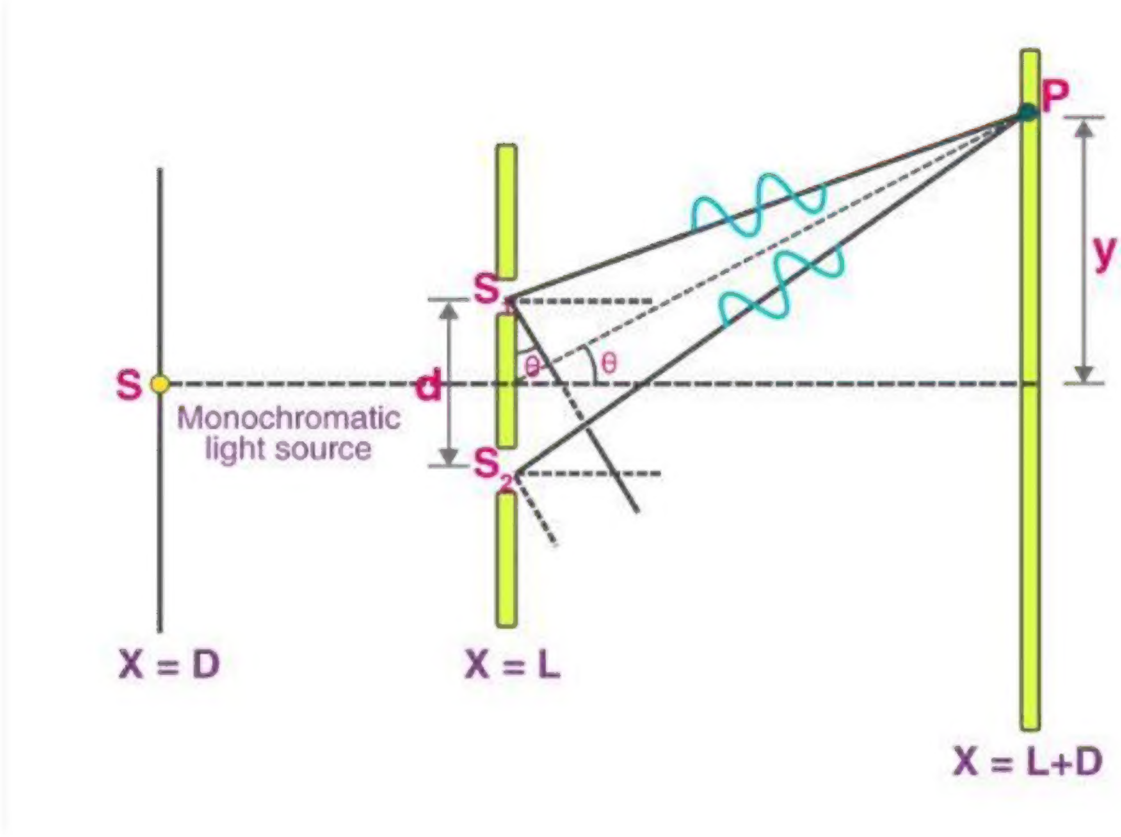
Two or more sources of light which do not emit light waves with a constant phase difference are called incoherent sources. Two independent sources can never be mutually coherent (are incoherent). A source of light consists of a large number of atoms and the emission of light pulses from various atoms is random and hence there is no constant phase relationship between two pulses

Derivation of Young's Double Slit Experiment

Consider a monochromatic light source 'S' kept at a considerable distance from two slits: s1 and s2. S is equidistant from s1 and s2. s1 and s2 behave as two coherent sources as both are derived from S.

The light passes through these slits and falls on a screen which is at a distance 'D' from the position of slits s1 and s2. 'd' is the separation between two slits.

If s1 is open and s2 is closed, the screen opposite to s1 is closed, and only the screen opposite to s2 is illuminated. The interference patterns appear only when both slits s1 and s2 are open.



When the slit separation (d) and the screen distance (D) are kept unchanged, to reach P, the light waves from s1 and s2 must travel different distances. It implies that there is a path difference in Young's double slit experiment between the two light waves from s1 and s2.

Approximations in Young's double slit experiment

Approximation 1:D > > d: Since D > > d, the two light rays are assumed to be parallel.

Approximation 2: $d/\lambda >> 1$: Often, d is a fraction of a millimetre, and λ is a fraction of a micrometre for visible light.

Under these conditions, θ is small. Thus, we can use the approximation $\sin\theta = \tan\theta \approx \theta = \lambda/d$.

∴ path difference, $\Delta z = \lambda/d$

This is the path difference between two waves meeting at a point on the screen. Due to this path difference in Young's double slit experiment, some points on the screen are bright, and some points are dark.

Now, we will discuss the position of these light and dark fringes and fringe width.

Position of Fringes in Young's Double Slit Experiment

Position of Bright Fringes

For maximum intensity or bright fringe to be formed at P,

Path difference, $\Delta z = n\lambda$ (n = 0, ±1, ±2, ...)

i.e., $xd/D = n\lambda$

or

$x = n\lambda D/d$

The distance of the nth bright fringe from the centre is

$xn = n\lambda D/d$

Similarly, the distance of the (n-1)th bright fringe from the centre is

$x\,(n-1) = (n-1)\lambda D/d$

Fringe width, $\beta = xn - x\,(n-1) = n\lambda D/d - (n-1)\lambda D/d = \lambda D/d$

$(n = 0, \pm 1, \pm 2, \ldots)$

Position of Dark Fringes

For minimum intensity or dark fringe to be formed at P,

Path difference, $\Delta z = (2n + 1)(\lambda/2)$ $(n = 0, \pm 1, \pm 2, \ldots)$

i.e., $x = (2n + 1)\lambda D/2d$

The distance of the nth dark fringe from the centre is

$xn = (2n+1)\lambda D/2d$

Similarly, the distance of the (n-1)th bright fringe from the centre is

$x\,(n-1) = (2(n-1) + 1)\lambda D/2d$

Fringe width: $\beta = x_n - x_{(n-1)} = (2n + 1)\lambda D/2d - (2(n-1) + 1)\lambda D/2d = \lambda D/d$

$(n = 0, \pm 1, \pm 2, \ldots)$

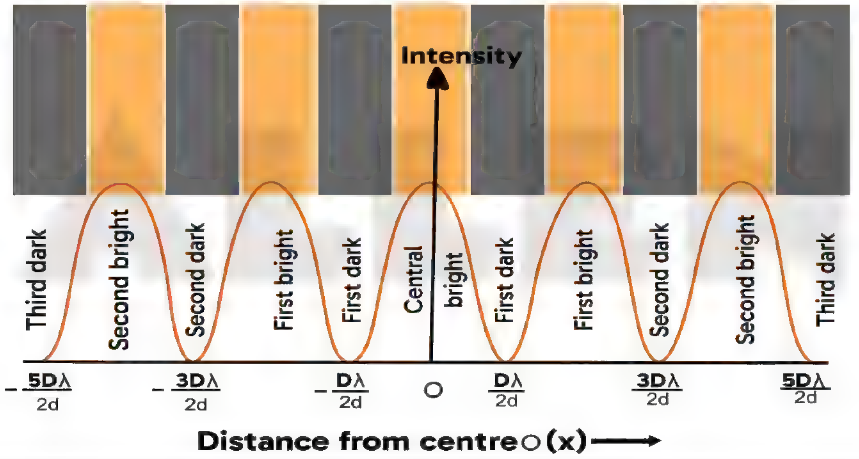
Fringe Width

The distance between two adjacent bright (or dark) fringes is called the fringe width.

$\beta = \lambda D/d$

If the apparatus of Young's double slit experiment is immersed in a liquid of refractive index (μ), then the wavelength of light and fringe width decreases 'μ' times.

If white light is used in place of monochromatic light, then coloured fringes are obtained on the screen, with red fringes larger in size than violet.



Constructive and Destructive Interference

For constructive interference, the path difference must be an integral multiple of the wavelength.

Thus, for a bright fringe to be at ‘y’,

$n\lambda = y\, d/D$

Or, $y = n\lambda D/d$

Where $n = \pm 0,1,2,3\ldots\ldots$

The 0th fringe represents the central bright fringe.

Similarly, the expression for a dark fringe in Young’s double slit experiment can be found by setting the path difference as

$\Delta l = (2n+1)\lambda/2$

This simplifies to

$(2n+1)\lambda/2 = y\, d/D$

$y = (2n+1)\lambda D/2d$

Young’s double slit experiment was a watershed moment in scientific history because it firmly established that light behaved like a wave.

The double slit experiment was later conducted using electrons, and to everyone’s surprise, the pattern generated was similar as expected with light. This would forever change our understanding of matter and particles, forcing us to accept that matter, like light, also behaves like a wave.

The Intensity of Fringes in Young's Double Slit Experiment

For two coherent sources, s1 and s2, the resultant intensity at point p is given by

$I = I1 + I2 + 2 \sqrt{(I1 . I2)} \cos \varphi$

Putting $I1 = I2 = I0$ (Since, $d <<< D$)

$I = I0 + I0 + 2 \sqrt{(I0.I0)} \cos \varphi$

$I = 2I0 + 2 (I0) \cos \varphi$

$I = 2I0 (1 + \cos \varphi)$

For maximum intensity

$\varphi = 2n\pi$

phase difference $\varphi = 2n\pi$

Then, path difference= $n\lambda$

The intensity of bright points is maximum and given by

$Imax = 4I0$

For minimum intensity

$\varphi = (2n - 1) \pi$

Phase difference $\varphi = (2n - 1)\pi$

Thus, the intensity of minima is given by

Imin = 0

If I1 ≠ I2, Imin ≠ 0.

Application of interference

Understanding Interference

- Interference is the phenomenon that occurs when two or more waves overlap and combine to form a new wave pattern. This can happen with any type of wave, but it is most commonly discussed in the context of light waves.

2. Optical Testing:

- One of the primary applications of interference is in optical testing. This involves using interference patterns to assess the quality of surfaces.

- Surface Quality Testing: Interference can be used to evaluate the smoothness and flatness of surfaces, such as optical lenses and mirrors.

3. Applications in Astronomy:

- Interference is also significant in the field of astronomy, particularly in radio astronomy.

- Radio Astronomy: Interference patterns help in analyzing signals from celestial bodies, allowing astronomers to gather data about the universe.

4. Measuring Light Intensity:

- Another important application of interference is in measuring light intensity.

- Light Intensity Measurement: This can be crucial in various scientific experiments and applications where precise light measurements are necessary.

5. Image Retrieval:

- Interference is utilized in telescopes for retrieving images.

- Image Retrieval from Telescopes: The interference of light waves can enhance the clarity and detail of images captured from distant astronomical objects.

6. Everyday Applications:

- Beyond scientific uses, interference has several applications in daily life, such as in the design of anti-reflective coatings on glasses and camera lenses, which utilize interference to reduce glare.

Summary of Applications:

- Optical testing for surface quality.
- Applications in radio astronomy.
- Measuring light intensity.
- Image retrieval in telescopes.

- Various everyday applications like anti-reflective coating